AN EXPERIMENTAL INVESTIGATION OF THE ELECTRIC FISH SENSORY AND DATA PROCESSING SYSTEMS DESIGNED TOWARD DEVELOPING PHYSICAL ANALOGS FOR HARDWARE PROTOTYPES HAVING SIMILAR CAPABILITIES

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Experiments Needed to Assess Sensitivity, Range and Effectiveness of the Electric Fishes to Detect Objects and Communicate Underwater

We consider it necessary to perform a number of experiments designed to quantify some of the electric fish properties. Four different species of electric fishes have been considered for these experiments because of their basically different systems used as transmitters and electroreceptors. These fishes are:

a. Gymnarchus niloticus

An African weakly fresh-water electric fish with a medium fixed frequency(260 to 300 Hz) and a composite waveform. Frequency does not change with temperature. It has about seven kinds of electroreceptors plus displacement, acoustic and chemical sensors located on or near the skin. Electroreceptors are located on the whole body but are more numerous near and on the head and near its very pointed tail. Countries or origin Sudan, Nigeria and Ivory Coast and the two Congos of Africa. It can grow to a maximum size of 5 feet and has a life span of about 40 years.

The electric organ is located caudally occupying about 1/2 to 2/3 of the fish length. Electric organ is derived from modified muscle spindels. Difficult to obtain and to keep alive. Has strange parasitic diseases affecting the spinal cord. The fish is blind and has only vestigial eyes.

b. Sternarchus albifrons

A South-American weakly fresh-water electric fish with a high, relatively fixed frequency (700-800 kHz) and a composite waveform. The rate of discharge is temperature dependent at a rate of between 40

to 60 Hz per degree centigrade. Has at least three kinds of electroreceptors plus displacement, acoustic and chemical sensors located on or near the skin. Electroreceptors are located on the whole body and preferentially on or around the head. Counties of origin: Brazil, Columbia, Venezuela, Guyanas, Argentina, Bolivia, Ecuador, Peru in South-America and some parts of Central America. Can grow to a maximum size of one foot. Life span is at least 10 years.

The electric organ is located candally occupying about 2/3 of the fishs' body length. The electric organ is derived from modified nervous tissue. It is a hardy species, easy to maintain and easy to procure. This fish is also blind and has vestigial eyes.

c. Gymnotus carapo

A South-American weakly fresh water electric fish with a medium - low variable frequency (30 to 150 Hz) and a composite waveform. Has multiple electro and sensory receptors located on or near the skin. Electroreceptors are located on the whole body and preferentially on or near the head. Counties of origin same as for Sternarchus albifrons. Can grow to a maximum size of one and a half feet. Life span is several years.

The electric organ is located caudally occupying about 1/2 of the fishs' body length. The electric organ is derived from modified muscle spindels. It is a hardy species but is not as easy to procure as Sternarchus.

d. Gnathonemus petersii

An African weakly fresh-water electric fish with a low variable pulse-form repetition rate signal (5 to 170 pps). Has multiple ampullary and tuberous electroreceptors and sensory receptors located on the body

and preferentially on or near the head. Counties of origin located in the subtropical, tropical and equatorial Africa. Can grow to a maximum size of one foot. Life span may be several years.

The electric organ is located in the tail and is derived from modified muscle tissue. (It is relatively easy to procure, but is very difficult to maintain it alive for longer periods of time in captivity.)

For all experiments we will use a fiberglass water tank of 12 ft diameter and 4 ft height.

Experiment #1 (B)

This experiment is designed to establish the ability of an electric fish of the species mentioned under (a) and (b) to detect metallic or non-metallic objects having different masses and introduced in the water tank at different distances from the fish. The fish will be held in a position A by a vertical nylon net. The nylon-net will be raised and the object introduced at position B. The time until the fish will detect the object will be noted by observing the fish which may retract or advance in the direction of the object, depending on the composition and mass of the object and on the species of the fish. This experiment will be repeated after lining the interior of the tank with aluminum foil (see Fig. 1). The objects considered are: iron, stainless steel (non-magnetic), wood, plexiglass, each in different dimensions (like 10 cm x 2 cm; 5 cm x 1 cm; 2 cm x 0.5 cm; etc). The objects will be fixed to a nylon thread and introduced vertically into the tank.

Experiment #2 (B)

This experiment is designed to assess the capability of electric fishes to use their navigation system to avoid obstacles like fine nylon

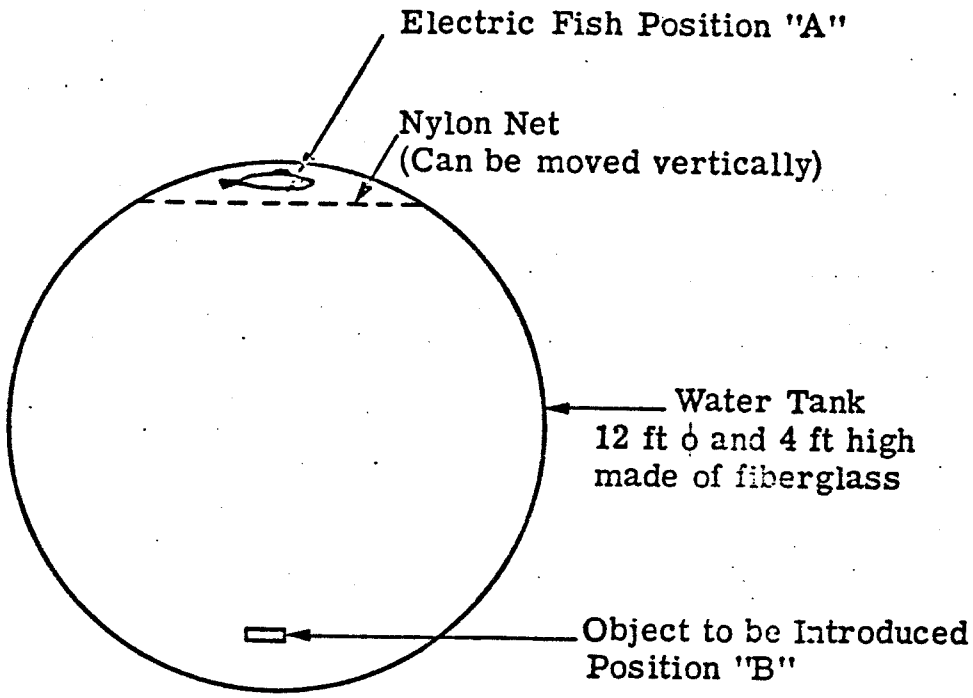


Fig. 1. The reaction time of the fish will be plotted against different masses of the same material type of object and for the same mass of different kind of object materials. A short film may be made to illustrate the reaction of the fish.

thread or fine wire (aluminum); copper cannot be used because copper even in minute quantities will kill these fishes. Again we will use fishes of the species mentioned under (a) and (b). Gymnarchus niloticus is an air breather and cannot be confined in a tube but it can be used in experiments with free swimming fishes. It is also a small goldfish eater. This fish will be put in the tank at the point "A" (see Fig. 2) behind a nylon net. A double net will divide the tank. A goldfish will be put in a nylon net bag and introduced in the tank at point "B" after the nylon net holding the electric fish has been removed. The reaction of the fish and the avoidance of the net will be observed and filmed. The fish species type (b) Sternarchus albifrons is not a fish eater but usually reacts with an escape to a metallic object. In this case a metallic object will be used to force the fish to cross the double net. Its avoidance of the obstacles will be noted and filmed. Both fishes are blind.

The experiment will be repeated using a grounded aluminum foil along the inner wall of the water tank.

Experiment #3 (B)

This experiment is designed to demonstrate the ability of electric fish to detect a magnetostatic field. The arrangement will be similar with experiment #1 but instead of using an object in the water we will use a permanent magnet outside the tank. Magnets of 10 kG, 1 kG, and 500 G, will be used at distances of 3 ft from the tank wall or near the tank wall at Position "B" or "C". The fish will be located at position "A" behind a nylon net (see Fig. 3). The magnetic field in the tank will be measured with a Hall-effect-probe and a Gaussmeter. The reaction of the fish to the magnetic field will be noted and filmed. The threshold of detection of

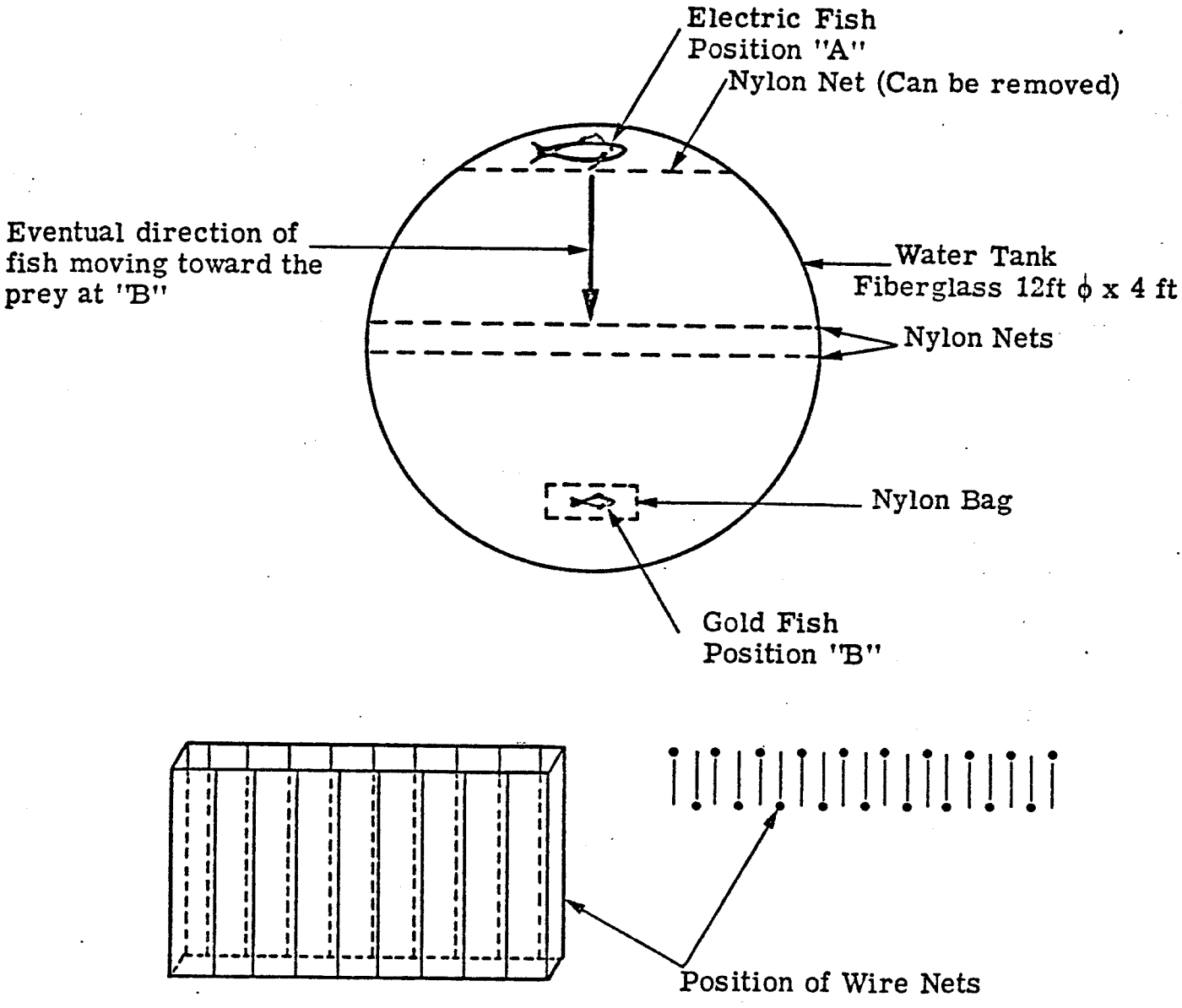

Electric Fish
Position "A"
Nylon Net (Can be removed)
Eventual direction of
fish moving toward the
prey at "B"
Water Tank
Fiberglass 12ft ϕ x 4 ft
Nylon Nets
Nylon Bag
Gold Fish
Position "B"
Position of Wire Nets

Figure 2.

the magnetic field by different fishes of the same species and of the average of different species will be plotted one against each other. The magnet will be also moved from "D" to "E" and the reaction of the fish observed.

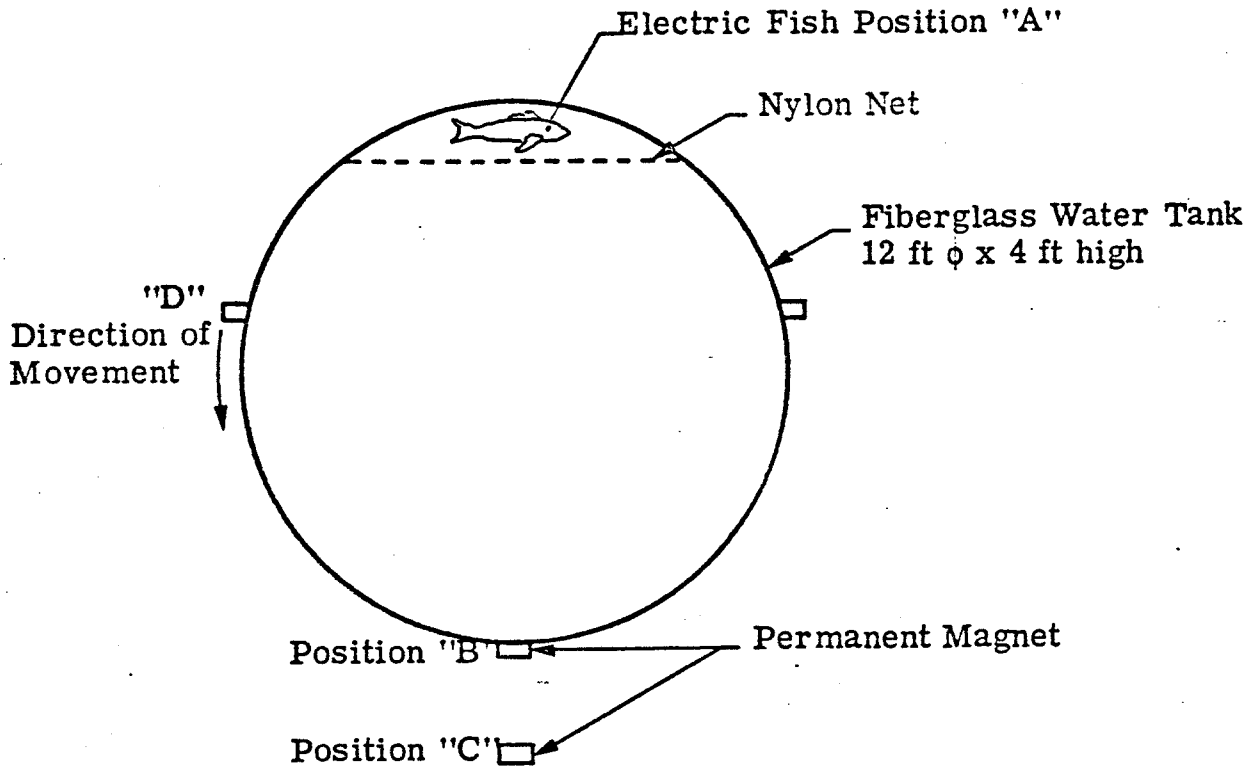


Figure 3.

The sensitivity of electroreceptors will be calculated, counting the number of electroreceptors per square cm and plotting it against the minimum magnetic field gradient that could be detected by the fish.

Experiment #4 (B)

This experiment is designed to demonstrate the ability of electric fishes to detect electrostatic fields. The arrangement for this experiment will be similar to the preceding experiment, #3, but instead of a permanent magnet we will use a sphere charged electrostatically to 100, 200, 400, and 1000 ESU and isolated on a teflon and plexiglass support. The gradient of the field generated by the charged sphere in the tank will be calculated. The threshold of reaction of the electric fishes (different fishes of the same species and different species) will be established (see Fig. 4).

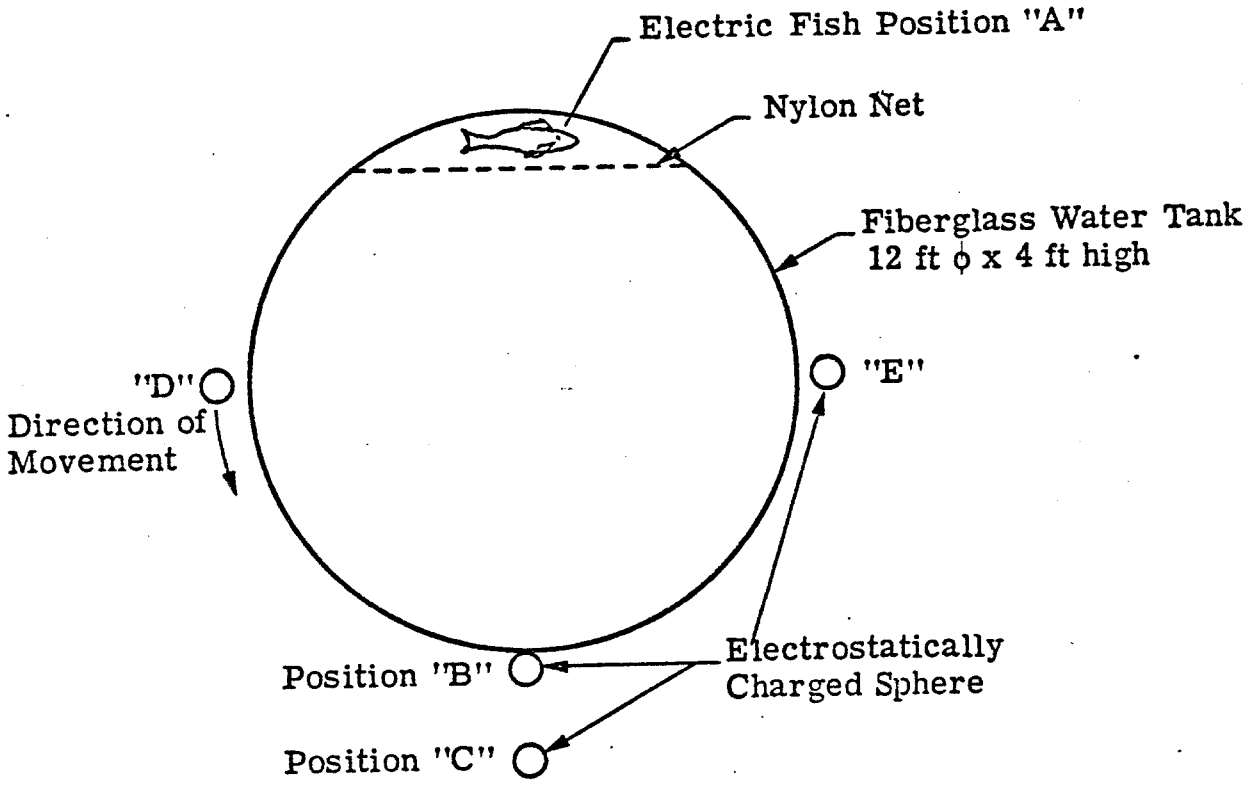


Figure 4.

The threshold of detection of the electrostatic field (stationary or moving) of different fishes of the same species against each other and the average of different species against each other will be plotted. The sensitivity of the electroreceptors will be calculated, counting the number of electroreceptors per square cm and plotting it against the minimum electrostatic field gradient that could be detected by the fish.

Experiment #5 (B)

This experiment is designed to assess the ability of electric fish to detect DC, AC repetitive signals, square wave and transient signals. The fish will be positioned behind a nylon net in the tank. Carbon electrodes will be put in the tank at the opposite end of the tank at one feet apart (see Fig. 5). The four experiments to be performed are as follows:

a. DC signals will be applied with a telegraph key monitored by an oscilloscope and attenuated by potentimeter and furnished by DC batteries. A resistance in series will limit the current (see Fig. 6). The reaction and threshold detection of the electric fish of the applied current/ and voltage will be noted. The gradient of the current will be calculated and a measurement of the voltage at the position where the fish will be put will be made prior to putting the fish in the tank with two carbon electrodes one foot apart. The threshold detection of the different fishes of the same species will be plotted one against another and the average of different species will be plotted also each against another.

b. The same procedure will be used to find the threshold of detection of AC sinusoidal current for frequencies of 5, 10, 20, 50, 100, 200, 500, 1000, 2000, 5000, and 10,000 Hz (see Fig. 7). The signals will be applied with nonpolarizable Ag, AgCl electrodes and measured with the same kind of electrodes. Also frequencies close to the fishes own frequency will be used.

c. Square waves of same repetition rate as the sinusoidal currents will be used and applied with Ag, AgCl electrodes.

d. The transients will be applied with the help of a network using a pulse transformer, resistors and a charged capacitor (see Fig. 8). The values will be calculated and the resulting waveforms will be measured with an oscilloscope. These signals will be applied also with Ag, AgCl electrodes.

The reaction and threshold of detection of the signals will be noted and plotted the same way as for DC current.

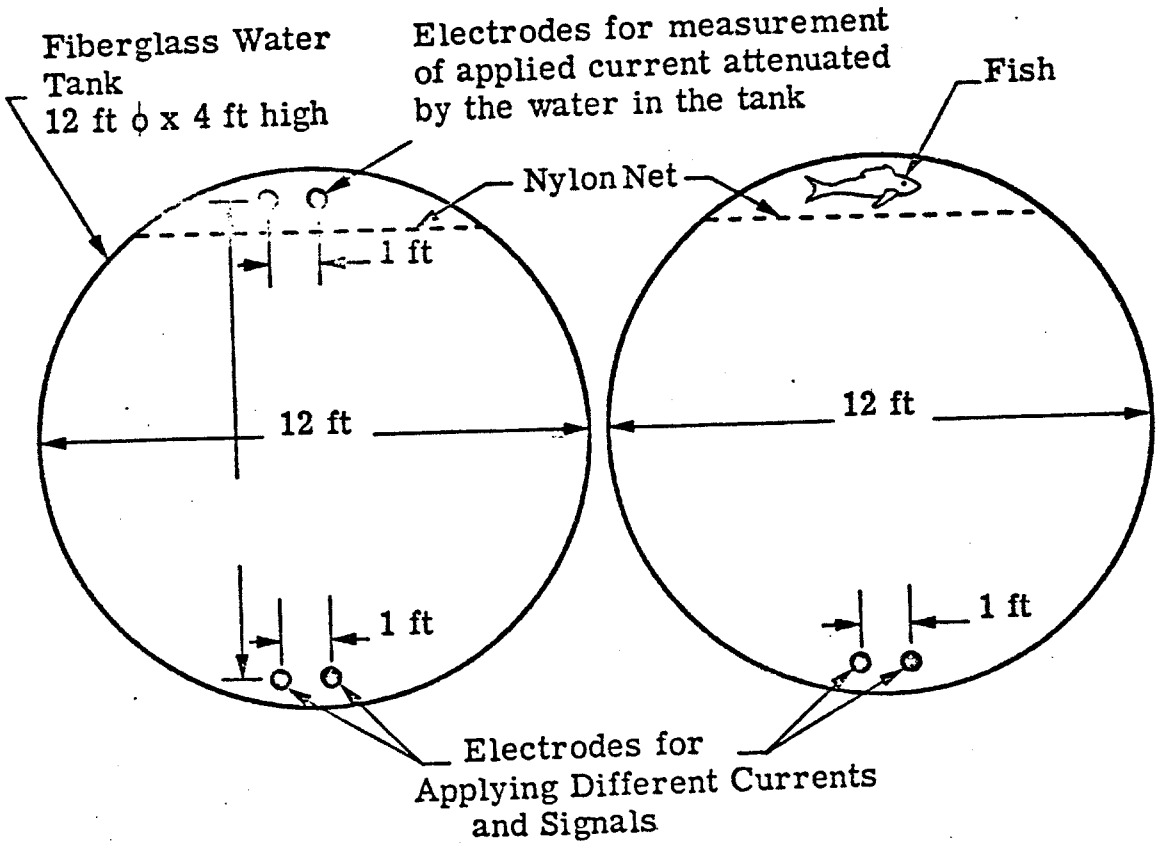
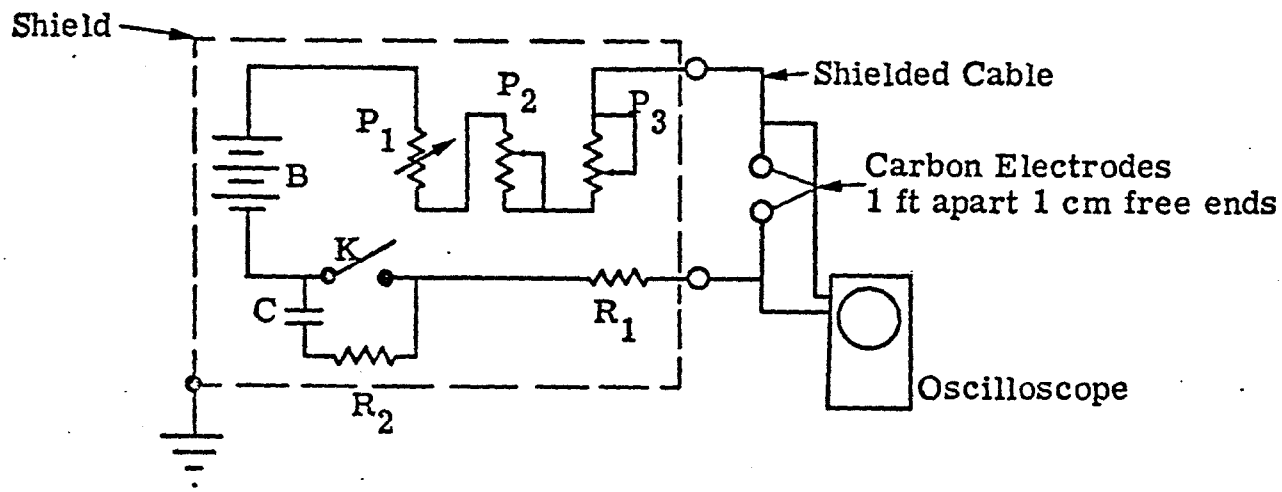


Figure 5.



B = Battery (optimum voltage will be determined by experiments but tentatively set between 2 and 6 volts)

P_1, P_2, P_3 = Potentiometers calculated to have constant impedance together with R_1 = resistor to correspond to the impedance of the carbon electrodes in water measured with the AC liquid impedance bridge

C and R_2 = capacitor and resistor to suppress sparks when the key is manipulated

k = key (telegraph type)

Fig. 6. DC signal system.

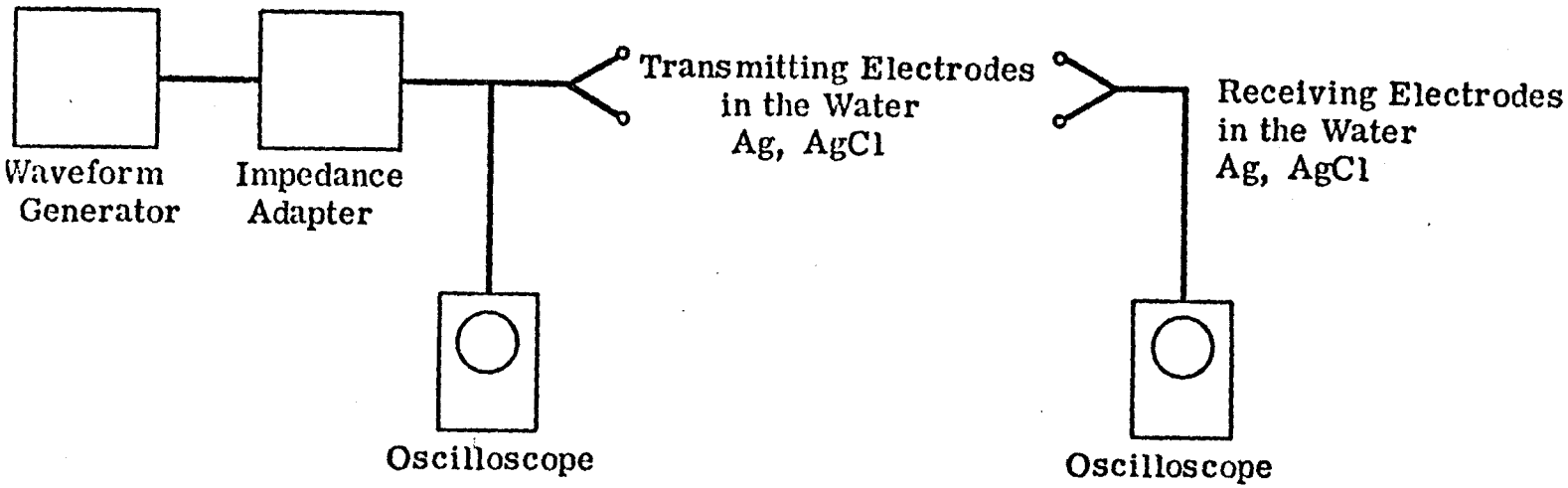
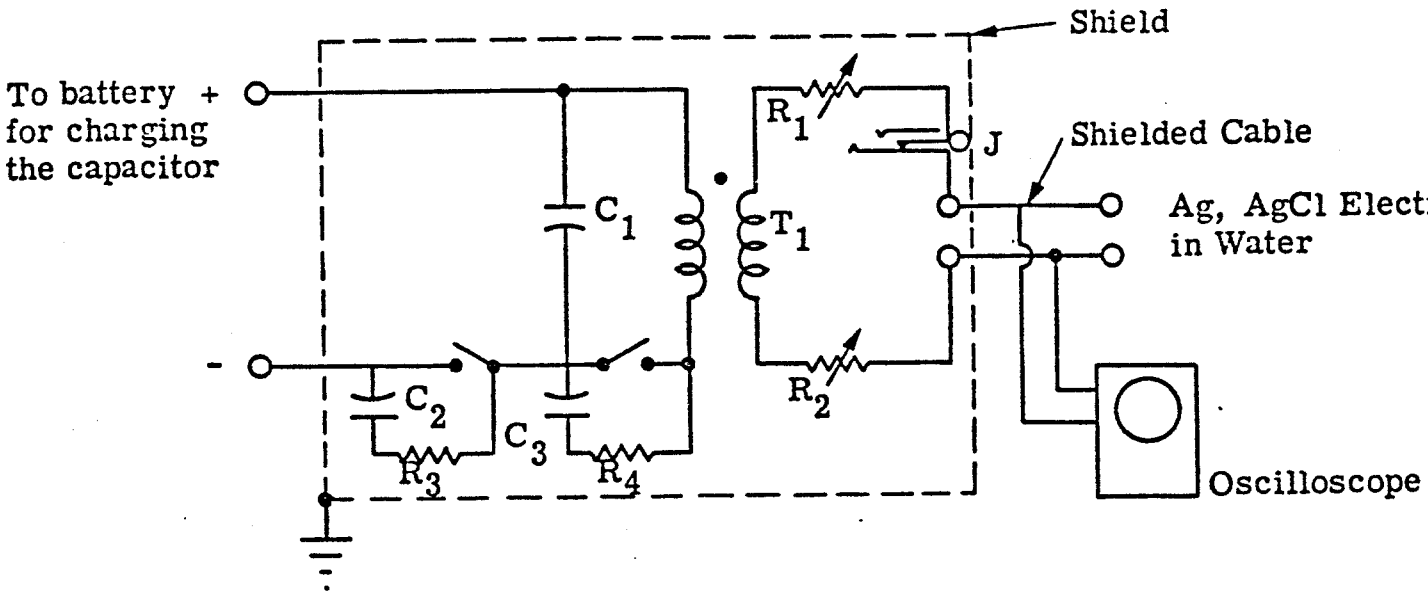


Fig. 7. Set-up for sinusoidal AC and square waves.



C_1 = High capacity tantalitic capacitor (value to be experimentally established according to the impedance of the electrodes in the water)

C_2R_3; C_3R_4 = Spark suppressing networks

R_1, R_2 = Variable resistors to adapt the circuit to the Ag-AgCl electrodes in the water

J = Jack for peak current measurement (with a resistor in series and an oscilloscope in parallel)

T_1 = Pulse transformer

Fig. 8. Transient generating set-up.

Experiments #1(P), 3(P), 4(P), and 5(P)

These experiments will be similar to the experiments 1(B), 3(B), 4(B) & 5B but instead of using free swimming fishes we will use fishes of species mentioned in "C" and "D" on page 2 like Gymnotus carapo and Gnothonemus petersii or equivalents restrained in a plexiglass tube with holes and two stainless steel electrodes at the end (see Fig. 9). Instead of observing the reaction of the electric fish to the different stimuli, we will monitor on the oscilloscope and frequency counter the charging rate, amplitude and waveform of the fish response to the stimuli. The latency and habituation will be noted. This time the graphs will show the relation between stimulus and response and also the threshold of reaction. With this species of fish and system a better quantification is possible of the ability of fish to detect objects, magnetic fields, electrostatic fields, DC currents, AC repetitive sinusoidal or squarewave signals and transient signals.

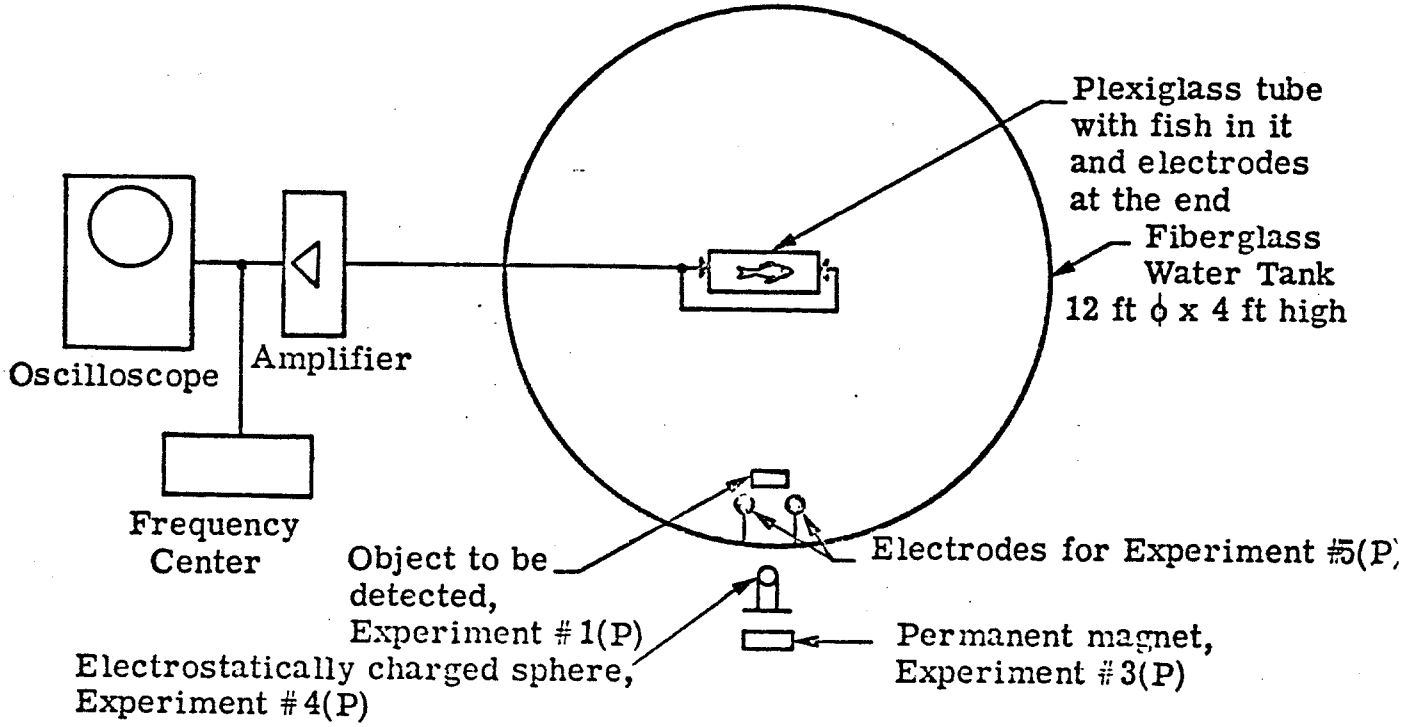

Plexiglass tube with fish in it and electrodes at the end
Fiberglass Water Tank 12 ft ϕ x 4 ft high
Oscilloscope
Amplifier
Frequency Center
Object to be detected, Experiment #1(P)
Electrostatically charged sphere, Experiment #4(P)
Electrodes for Experiment #5(P)
Permanent magnet, Experiment #3(P)

Figure 9.

Experiment #6

This experiment is designed to relate the ability of electric fishes to communicate underwater and the distance at which they can manage it (see Fig. 10). The natural noise and the signal strength of the fish will be measured. The original signal will be recorded with electrodes on a magnetic tape recorder and monitored on an oscilloscope. This signal will be played back with the aid of two carbon electrodes in the tank at a place "f" at the distance "l" from the fish situated at the point "g" and confined there with a nylon net. The reaction of the fish to its own signal will be observed and eventually filmed. The signal will be subsequently attenuated to precalculated attenuations corresponding to distances of 100 ft, 500 ft, 1000 ft and 5000 ft. If the fish will not react to a certain attenuation a variable attenuation in between the fixed points will be used to assess the distance at which the fish can detect its own signal. Also later noise will be introduced in the form of white noise and its effect on the ability of the fish to detect its own signal will be observed. At the end graphs will be plotted for the signal to noise ratio versus distance of signal detection.

The field generated by the electric fish will be calculated and plotted on a graph.

The experiments #1B, 2B, and 3B will be made in the fiberglass tank as it is and with aluminum foil set around the inner wall of the tank and grounded. The results with or without the grounded aluminum-foil will be plotted on graphs and eventually graphs will be plotted for the differences in results with and without grounded aluminum foil.

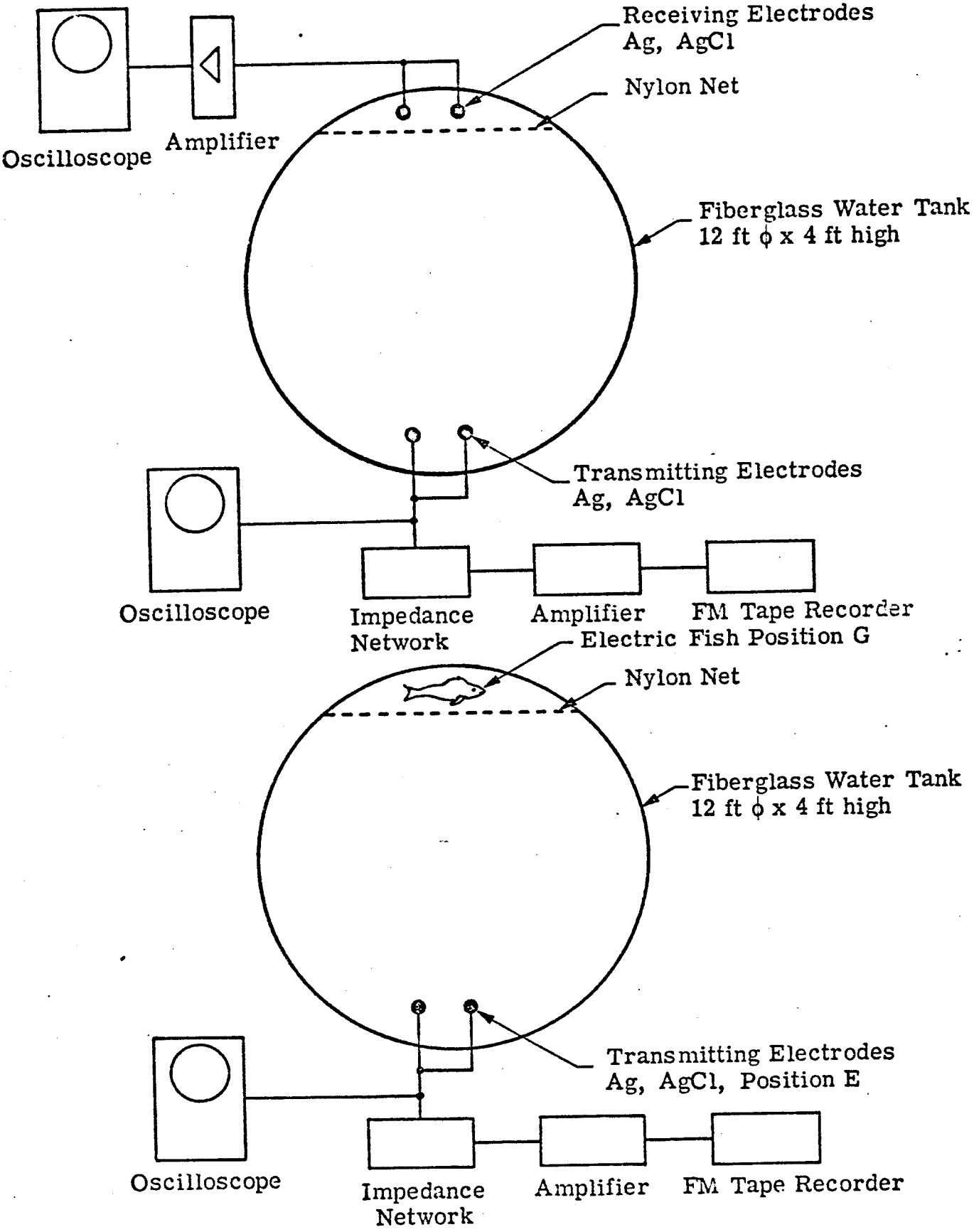

Receiving Electrodes
Ag, AgCl
Nylon Net
Oscilloscope
Amplifier
Fiberglass Water Tank
12 ft ϕ x 4 ft high
Transmitting Electrodes
Ag, AgCl
Oscilloscope
Impedance
Network
Amplifier
FM Tape Recorder
Electric Fish Position G
Nylon Net
Fiberglass Water Tank
12 ft ϕ x 4 ft high
Transmitting Electrodes
Ag, AgCl, Position E
Oscilloscope
Impedance
Network
Amplifier
FM Tape Recorder

Figure 10.

Experiment #7

In this experiment the electromagnetic field around some electric fishes (the ones which can be confined in a tube) will be measured and compared with values resulting from the calculated field.

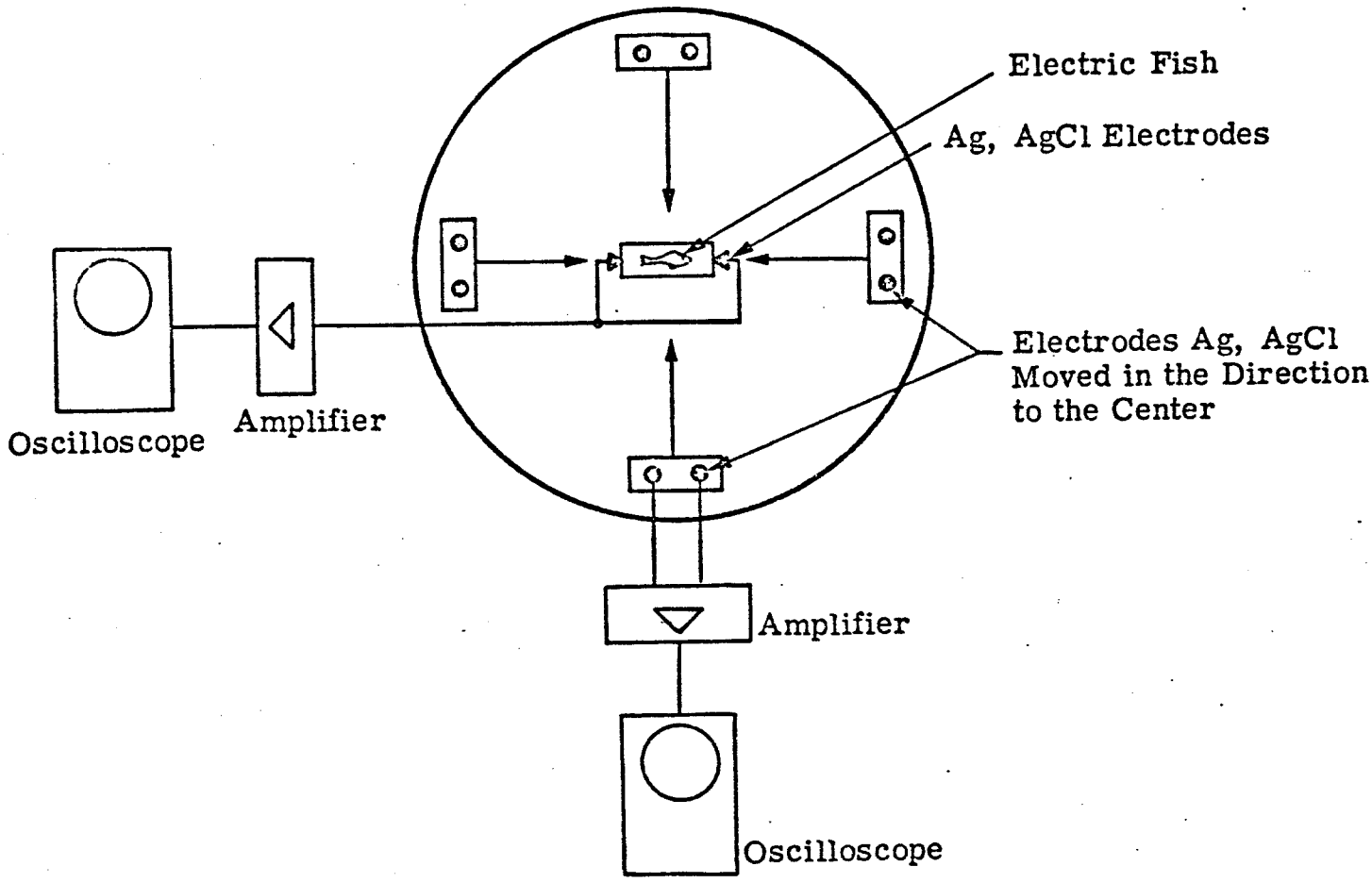


Figure 11.